ENGINES & ENERGY CONVERSION LABORATORY

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Knowledge to Go Places

Energy Lab Memo

To:	Jacek Popiel, Sturman Industries
From:	Bryan Willson Professor, Department of Mechanical Engineering Director, Engines & Energy Conversion Laboratory
Date:	July 28, 2005
Subject:	Self-Optimizing Diesel Engine for Variable Fuels

Concept

A concept is proposed to demonstrate continuous self-optimization of a diesel engine operating on various fuels using the high degree of adaptability afforded by hydraulic valve actuation (HVA) and advanced rate-shaping common-rail fuel injection.

Introduction

A diesel engine operates by injecting fuel directly into the cylinder of an engine when the piston is close to top dead center. The fuel mixes with the high temperature air in the cylinder and ignites after a characteristic induction time, called the "ignition delay". Optimal engine operation (efficiency, emissions, power, noise) requires closely matching engine design parameters (compression ratio, charge density, exhaust residual), fuel parameters (surface tension, viscosity, density, energy content, volatility, flash point), and fuel injection parameters (pressure, quantity, injection rate, timing).

Diesel engines are typically optimized to operate only on one fuel - the "standard" diesel fuel known as DF-2. There is a wide range of fuels that could be used in diesel engines, but do not work well in engines optimized for DF-2. Civilian aviation fuels (Jet A1, Jet A, Jet B) and military fuels (JP-4, JP-5, JP-8) are theoretically suitable for use in diesel engines, but require modifications to the engine and fuel system to run well. Of particular note is the military's interest of standardizing on JP-8 as a single fuel for all applications. Other fuels which are receiving increasing attention are "biodiesel" and "synfuels" (synthetic fuels) such as Fischer-Tropsch diesel. The characteristics of biodiesel can vary widely due to the type of feedstock (canola, soy, mustard, rapeseed, karange, etc), the type of processing, and the degree of "esterification". The biodiesel fuels currently being marketed for public sale are blends, containing only a small fraction (typically 5%-10%) of the biologically derived fuel. The properties of Fischer-Tropsch fuel are dependent on the feedstock (coal, natural gas), and the processing technique.

An engine designed for a high-cetane DF-2 fuel may perform very poorly on a low-cetane Fischer-Tropsch fuel. However, the capabilities afforded by HVA and high-authority, rate-shaping, common-rail fuel injection would allow an engine to operate optimally on a wide range of fuels. This capability would afford strategic advantage for military vehicles. It would also allow operation on a wide range of "regional fuels", which would increase the energy options for civilian engine / vehicle applications.

Technology

Optimization of a diesel engine for a particular fuel requires alteration of both the engine and the fuel system. Sturman's HVA camless engine technology provides significant capability to vary the engine's trapped mass, compression ratio, exhaust gas residual, charge temperature, turbocharger boost and turbulence levels. Sturman's S1 fuel system provides the ability to vary fuel timing, pressure, and fueling rate. The S1 system is capable of delivering tiny "pilot injections" (delivered before the main injection to reduce ignition delay); then deliver a main injection with either a rising, falling, or arbitrary injection rate; and then deliver "post injections" for soot reduction, to assist exhaust aftertreatment, and to control turbocharger boost. A control system to integrate these capabilities would utilize advanced sensing (ionization sensing, combustion pressure sensing, optical sensing, etc.), advanced self-optimizing control techniques (self-tuning model-based control, reinforcement learning, neural networks, genetic algorithms, etc.), and advanced computational hardware (digital signal processors, field programmable gate arrays, high speed on-vehicle communications networks, etc.).

Project Concept

Sturman's camless engine and fuel injection systems are the industry's technology leaders. However, an engine has never been built which fully integrates the flexibility of Sturman's most capable HVA technology and their most capable fuel injection technology. It is proposed that these two technologies be integrated through the use of advanced adaptive engine control techniques. The end product will be a demonstration engine which has the ability to operate optimally on the widest possible range of fuels, including military fuels, biofuels, and synthetic fuels.

Operational Scenario

One can picture a scenario in which a truck with a military cargo drives across the country. Beginning on the East Coast with a tank filled with DF-2, the truck then refuels with biodiesel as it drives across the Midwest, operating successively on high-fraction blends of fuels manufactured from soy, canola, mustard, and rapeseed. As the truck drives across the West, the region's mineral resources allow the truck operates on Fischer-Tropsch fuels produced from coal and natural gas. Although the fuels have very different chemical composition and combustion properties, the self-optimizing engine works continuously to vary the valve and fuel injection characteristics so that the engine maintains optimal efficiency and ultra low emissions. Finally, after delivery the cargo in California, the truck refuels with JP-8 fuel on the military base and begins the return trip home. The capabilities afforded by the self-optimizing engine allow it to meet stringent emissions regulations and still operate at maximum efficiency.

The scenario demonstrates the benefits of a self-optimizing engine for civilian applications. There are even greater benefits for military applications. Although the military would prefer to operate on a single fuel (JP-8), there would be enormous strategic benefits to being able to operate on locally available diesel fuel or on other fuels such as kerosene, palm oil, etc. And the engine's flexibility would allow a vehicle to operate with minimum emissions, maximum efficiency, or the highest possible power – depending on the mission at any particular time.